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Investigation into the Semantic Density and Semantic Gravity Wave Profile of Teachers When Discussing Electrophilic Aromatic Substitution (S_EAr)

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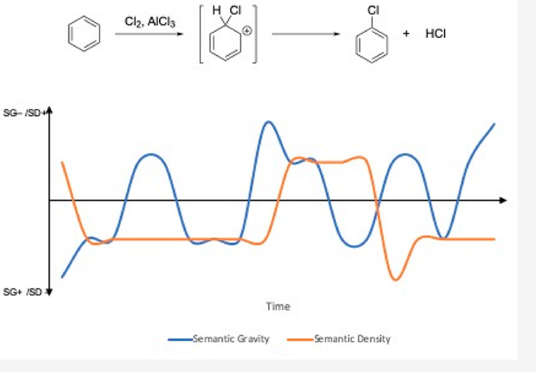

ABSTRACT: Language in chemistry is highly specialized, and for students, transitions in language complexity from high school to university can be extremely challenging. With an increasingly diverse cohort of students enrolled in UK chemistry degree programs, better understanding the linguistic challenges students face is becoming a greater pedagogical priority. Spoken language plays a central role when learning chemistry, and any misunderstandings can lead to misconceptions that can impede students' success in this demanding subject. This small-scale study sought to compare the complexity of spoken-language explanations of the same chemical process within UK secondary (high school) and university contexts. The study involved seven organic chemistry educators/teachers, four based in a UK university and three in a UK high school, discussing electrophilic aromatic substitution (S_EAr) via a lecture or screencast. The participants' spoken discourse was transcribed and coded according to the concepts of semantic gravity (the degree to which meaning relates to context) and semantic density (the degree to which meaning is condensed within symbols) drawn from Legitimation Code Theory, and then it was analyzed for semantic waves. When considering semantic gravity, there were some similarities and some differences. In all cases, semantic gravity was weaker, but participants based in a university environment generally tended to exhibit relatively weaker semantic gravity than their school-based counterparts. The school-based participants usually added further explanations to clarify what was meant during an explanation and exhibited semantic waves by unpacking and repacking a concept, whereas the university-based participants tended to show a flatter semantic profile. Findings showed that, across the levels of study investigated, semantic density was stronger: a similar complexity of chemistry-specific vocabulary used by all seven participants, regardless of the audience. Findings have pedagogical implications and suggest that a larger-scale study of semantic waves in oral chemistry discourse could usefully inform specific-purposes language teaching.

KEYWORDS: *General Public, Chemistry Education Research, Communication/Writing, Aromatic Compounds*

FEATURE: Chemical Education Research

INTRODUCTION

Subject-Specific Language within Organic Chemistry

Successful study in chemistry requires "vertical integration" of knowledge, with the learning and understanding of basic concepts and ideas acting as foundations for further study.[1−3] Organic chemistry is particularly challenging because when learning about reactions and transformations there are two aspects that students need to master in order to succeed. First, students need to become proficient with the subject-specific language used, and second, students need to become fluent at using and understanding visual representations of reactions and chemical transformations.[4−7] Kozma and Russell[8] show that the ability of students and instructors to represent chemical happenings in different ways is important, and they suggest that language has a key role in holding different representations together.

Language used when teaching chemistry is complex: everyday words have different meanings, and a large number of complex Greek and Latin words are embedded within chemistry terms. Technical language has to be used carefully so that meanings are not lost or altered.[9] Bernstein characterizes the language of chemistry as "vertical discourse" and states that "...vertical discourse takes the form of coherent, explicit, and systematically principled structure, hierarchically organized as in the sciences, or it takes the form of a series of

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specialized languages with specialized modes of interrogation and specialized criteria for the production and circulation of texts, as in the social sciences and humanities".[10] The latter criterion can also be applied to the natural sciences. This definition of vertical discourse suggests that in a hierarchical subject, such as chemistry, language used is not segmentally organized, as it would be in horizontal discourse, but that procedures or concepts are linked to other procedures or concepts.

Jacob[11] suggested that there are four levels in chemical language, with each level increasing in abstraction with epistemological and linguistic characteristics. The first level (L1, symbolic) represents the chemical symbols, formulas, and equations used, and the formal and semantic rules that govern their use. The second level (L2, relational) includes the vocabulary required to discuss substances and chemistry in general and contains abstractors such as the terms "element" and "compound". The third level (L3, modelic) contains the terms to discuss the abstractors in relation to laws, models, or theories. The fourth and final level (L4, epistemic) represents the language of chemistry and the scientific epistemological discussions as a whole, for example, chemical theories, their origin, and empirical basis. Jacob suggests that a reaction mechanism, as a linguistic representation of a chemical reaction, belongs to the epistemic level.

Lorenzo, Farré, and Rossi[12] undertook a study to link chemical language with discourse analysis. Ten university-level organic chemistry teachers' lectures were recorded, and the ways they described new information in terms of univocal (transmitting meaning) or dialogic (dialogue to generate new meaning) were analyzed. It was noted that when explaining organic chemistry, the teachers did not relate their lectures to laboratory practice or everyday life, and new terms were generally defined with other technical words. Teachers generally undertook long monologues, added anthropomorphic features to the chemicals, and presented subject material without further information to complete or illustrate a context. Expository discourse, or explaining an outcome in a matter-of-fact way, dominated their explanations of organic chemistry.

Legitimation Code Theory: Semantic Gravity, Sematic Density, and Semantic Waves

Vertical discourse and Bernstein's knowledge structures are supported by a conceptual framework called "Legitimation Code Theory" (LCT), which is widely used within sociology, education, and linguistics.[13−15] LCT is a tool that measures the degree of abstraction and/or the degree of complexity in a particular meaning, and it is usually applied to written prose.[16] The degree of abstraction is called semantic gravity (SG) and is defined as *the degree to which meaning relates to context*. The strength or weakness of semantic gravity is related to how concrete or abstract a concept is; a concept with stronger semantic gravity is termed SG+ and is taken to mean something that is less abstract. For example, it is factual or can be observed. Semantic density (SD) is defined as *the degree to which meaning is condensed within symbols*, and is used to define how complex a concept or word/phrase is. Stronger semantic density (SD+) means that there is more complexity in a word or phrase.

Semantic gravity and semantic density are independent and may strengthen and/or weaken producing semantic codes (SG ± , SD±). Maton represents these semantic codes on a set of Cartesian axes (Figure 1).[17] These codes may be present in

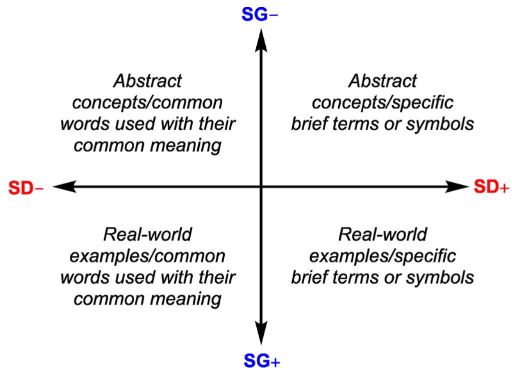

Figure 1. Semantic plane. SG means semantic gravity, and SD means semantic density.

different combinations generating four possible modalities: rhizomatic codes (SG−, SD+), prosaic codes (SG+, SD−), worldly codes (SG+, SD+), and rarefied codes (SG−, SD−). The rhizomatic codes (top right quadrant) require the most advanced level of application by the learner. Where the axes cross may change as one becomes more of an expert. Semantic density and semantic gravity are independent of each other. For example, if a concept is abstract or requires students to link two or three theories (SG−) but the language used to describe it is not necessarily complex (SD−), the designation would be (SG−, SD−). The discourse would be categorized as "rarefied code". Another example would be the use of complex language (SD+) to describe a relatively simple phenomenon (SG+). In this case, the discourse would reside in the "worldly code" quadrant. For an outline of chemistry-specific examples, please see Blackie's recent work.[18]

The context in which the terms are used may alter their meaning. For example, the term "alcohol" when used everyday conversation usually refers to beer, wine, or another beverage that contains ethanol. However, within chemistry the term alcohol can have a range of underlying meanings. For example, the alcohol itself may be primary, secondary, or tertiary, and in the presence of a metal it can form a salt. If the term "alcohol" is mentioned in a lesson or a lecture, the student rapidly has to ascertain which aspect of the alcohol is important and focus on that. Alcohol in a chemistry sense can be argued to have a stronger semantic density than in an everyday sense.

Analysis of semantic density and semantic gravity over an extended period can lead to a semantic profile. For example, if we consider semantic gravity in a situation where the discourse is consistently embedded in context (e.g., a color change in a reaction) and there is little discussion of new concepts, ideas, or theories, the semantic gravity is stronger (SG+) and likely to stay as a low, flat line. However, it could be argued that the discussion of curly arrows and electron movement to form bonds or a product during the same reaction is abstract and requires learners to unite two or more underlying theories or principles. This explanation would therefore exhibit weaker semantic gravity (SG−). Accordingly, when explaining to students a particular reaction and the associated mechanism, semantic density and semantic gravity may weaken and strengthen over time, leading to semantic waves.

It should be noted that use of the term "semantic gravity" within chemistry needs to be treated with caution, because when describing chemical reactions and chemical phenomena, we are usually already working at a high degree of abstraction

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J. Chem. Educ. XXXX, XXX, XXX−XXX

or complexity. Blackie states that "understanding reaction mechanisms in organic chemistry requires a level of familiarity with the periodic table, with bonding, with hybridization, molecular orbital theory etc. When we consider the idea of semantic waves in chemistry, we need to consider the temporal wave as well. How does this section of chemistry which I am currently teaching connect with what has gone before, and what is it building towards?"[18]

Legitimation Code Theory (LCT) and English for Academic Purposes Research within STEM Subjects

There are some examples where LCT has been used within STEM subjects to analyze a variety of different media: Macnaught, Maton, Martin, and Matruglio have explored the application of LCT in high school biology teacher training;[19] Georgiou, Maton, and Sharma have analyzed semantic gravity in tertiary students' responses to thermal physics questions;[10] and Rootman-le Grange and Blackie analyzed a first-year chemistry exam paper.[20] Kelly-Laubscher and Luckett used LCT to compare the semantic gravity and semantic density of two South African textbooks: one designed for high school and one for the first year of university.[21] Semantic density and semantic gravity were considered independently of each other, and each paragraph was designated according to the highest semantic density or gravity present. They found that the university-level textbook exhibited stronger semantic density (SD+) and a greater range of semantic gravity than the high school text, and that, on average, the high school textbook resided in the prosaic code quadrant (SG+/SD−) and the university textbook in the worldly code quadrant (SG+/SD+). Responding to the findings of Kelly-Laubscher and Luckett, Mouton and Archer used LCT to analyze a first year university lecture course and then redesign it such that the semantic gap between high school and the first year of university was narrowed.[13] In lectures before the redesign, the semantic density was often stronger (SD+), but semantic gravity was weaker (SG−), and students' prior learning was not taken into account. After the redesign, the lectures contained semantic waves, where concepts were "unpacked" and "repacked" over time. Importantly, the explicit use of semantic waves showed an improvement of the understanding of students and a significant improvement in the average marks of the cohort in summative assessment questions.

While there have been LCT studies investigating semantic gravity, density, or both, in STEM subjects in individual spoken-language educational contexts, in student exam responses and in exam design, and in contrasting written language educational genres at different levels in STEM, to the best of our knowledge no studies have to date contrasted spoken language across educational levels in STEM. Furthermore, as demonstrated by Mouton and Archer,[7] attending to semantic gravity and density and to the extent of semantic "waving" within educational contexts can lead to pedagogical revisions that positively impact student learning. Therefore, a contrastive LCT analysis of spoken STEM discourse will both extend existing understandings of semantic gravity and density in STEM discourse and potentially highlight useful pathways for pedagogical revisions.

In English for Academic Purposes (EAP) research investigating the language of chemistry, a similar gap exists with regard to understanding of oral communication in the discipline. A number of studies have investigated aspects of research writing including verb use,[22] field-specific vocabulary,[23] and genre features.[24,25] Two studies by Kashiha and Heng have looked comparatively at both the linguistic structure[26] and discourse function[27] of lexical bundles (strings of words that commonly co-occur in natural discourse) in lectures in the disciplines of politics and chemistry, making use of four lectures from each discipline from the British Academic Spoken English corpus. Kashiha and Heng found that discourse organizer bundles, which reflect the relationship between prior and coming discourse, were used slightly more in politics and stance bundles, which express attitudes of assessments of certainty that frame another proposition, slightly more in chemistry. Both disciplines made frequent use of referential bundles (bundles that make direct reference to physical or abstract entities; vis-à-vis weaker semantic gravity).[21] However, their studies only include spoken discourse samples from higher education and do not take into account the level of study or subject matter.

■ AIMS OF THE CURRENT STUDY

This study will contrastively analyze spoken discourse across high school and first-year university levels with regard to levels of semantic density and semantic gravity, and the extent of semantic "waving" used when explaining electrophilic aromatic substitution of benzene with chlorine (S_EAr) to derive a semantic profile. It should be noted that this study focuses only on the language used by the participants and does not attempt to probe the relationship between spoken discourse and reference to diagrams (intersemiosis). It is hypothesized that high school discourse will exhibit stronger semantic gravity (SG+) and weaker semantic density (SD−) and exhibit greater incidence of semantic waves due to unpacking and repacking of concepts. Comparatively, we expected that the university-level participants would exhibit weaker semantic gravity (SG−), due to linking many complex ideas and explanations, and stronger semantic density (SD+) due to their use of more complex vocabulary.

■ METHODS AND FRAMEWORK

In order to investigate similarities and differences between the semantic gravity and semantic density of spoken explanations of chemistry at secondary and higher education (HE) levels, a comparable sample of spoken chemistry discourse at each level was needed. Seven teachers of chemistry agreed to participate in the study. Four participants worked at university, and three taught in a secondary school (see Table 1). Of the seven participants in this study, five held a PhD in organic chemistry, and one a PhD in biochemistry.

Seven teachers (5 male, 2 female) recorded themselves (audio and visual) teaching electrophilic aromatic substitution of benzene with chlorine (S_EAr), Table 1. Two sessions were recorded "live", in front of a student audience, and five were

Table 1. Participants in This Study

	Participant	Level	Length of Explanation(s)
University	A	University	538
	B	University	355
	C	University	531
	D	University	590
School	E	School	334
	F	School	183
	G	School	283

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J. Chem. Educ. XXXX, XXX, XXX−XXX

Table 2. Language for Description of Mechanisms within Organic Chemistry: Semantic Gravity

Strength of Semantic Gravity	Description	Example Taken from the Transcripts Analyzed
SG−−	New concepts or theories linking two or more ideas. May include discourse about curly arrows/electron movement.	"Those π-electrons are in a carbon−carbon bond adjacent to the carbocation, so by moving π-electrons across from this carbon to a new carbon−carbon double bond we can draw another resonance form."
SG−	Link back to generalizing principles or previously learnt things, either in curriculum or in mechanistic explanation.	"In π-bonds, the electron density of exists above and below the plane of the benzene-molecule. Benzene is planar so the π-electrons exist both above and below the plane."
SG+	Information about general concepts or the simple outcome of an experiment, i.e., cause and an effect	"A dipole is induced within that chlorine molecule because the electron density of the chlorine−chlorine bond is repelled..."
SG++	Concrete example, experiment, or comment related to context. Refers to/points to structure.	"If we think about a benzene-ring, we've got this 6-membered carbon ring-system."

Table 3. Language for Description of Mechanisms within Organic Chemistry: Semantic Density

Strength of Semantic Density	Description	Example Taken from the Transcripts Analyzed (Words Deemed Complex Are in Italics)
SD++	Five or more advanced, chemistry-specific terms needs to be manipulated or unpacked before the student can start to understand the explanation.	"Looking at *benzene* it looks like a kind of *cyclic-triene* with three *alkenes* in this *cyclic-arrangement* here, but you know that *benzene* has *aromatic-stability* so if we count the number of *π-electrons*..."
SD+	Three or four advanced, chemistry-specific terms are used in conjunction that need to be manipulated or unpacked before it can be interpreted.	"So in this reaction we have *benzene* shown here reacting with chlorine to form *chlorobenzene* and HCl. So we need to use *aluminum trichloride*, or a similar *species* to get this reaction to go."
SD−	Only one or two advanced, chemistry-specific terms are needed to understand the explanation.	"The most important thing is that there is a break in the *π-system*"
SD−−	No advanced, chemistry-specific terminology or concepts required to understand the explanation.	"Just make sure you draw something that looks like that"

screencasts. The length of the discussion ranged from 183 to 590 s. Of the university participants, one taught solely on a foundation program (participant D), and the remaining three taught to years 1−4 of an undergraduate program, with one participant also teaching postgraduate courses (participant C). In the UK, a foundation program is a year that students complete prior to starting their year 1 studies if they do not fulfill the correct academic requirements for joining a university degree program directly.

The spoken-language input chosen for analysis was lecture-style explanations of organic chemistry concepts. In order to ensure that any differences in complexity of the explanations identified could as far as possible be attributed to level rather than to other factors, the same content-focus was analyzed across both levels of study. The concept chosen was electrophilic aromatic substitution (S_EAr) because it is encountered during the second year of A-level study (exams completed in the UK aged 18 in high school) and is usually covered again in the first year of an undergraduate university chemistry degree, which would allow for comparable data. To explain electrophilic aromatic substitution to students, a large amount of chemistry-specific terminology needs to be used; this is often derived from Greek phrases and is unlikely to have been encountered in students' previous study. In addition, the concept of electrophilic aromatic substitution is somewhat abstract because concepts and ideas need to be linked to understand an explanation, and at this stage, there is usually a substantial amount of discourse relating to electron movement and bond formation/breaking, concepts that students often find difficult.[28−32]

Two screencasts were recorded specifically for this study, and two were already used by the participants as supporting information for their lectures/lessons. The "live" sessions were regular lectures/lessons and were recorded using a smart-device. In all cases, students were assumed to have some prior knowledge of the mechanisms discussed; in the UK, students first learn about S_EAr during A-level and then again during year 1 of university. Audio recordings were transcribed manually by the authors of this study. Natural breaks were used as indicators for the start a new paragraph or sentence. When coding and analyzing transcripts, filler words, for example "um" and "uh-huh" were ignored. All participants described themselves as "very confident" teaching S_EAr and explicitly gave their informed consent for the author to use their data in publication.

When coding for semantic gravity, the translational device in Table 2 was used, which was based upon previous work.[13−15] Stronger semantic gravity (SG++) was conceptualized as something that was related to fact and could be easily recalled or understood. The example given in Table 2, "if we think about a benzene-ring we've got this 6-membered carbon ring-system", is a statement of fact that does not require further understanding by the student and does not link to any previously taught concepts. Semantic gravity was weaker (SG−) when students needed to link back to general concepts discussed earlier in either the curriculum or course, and semantic gravity was even weaker again when two or more previously encountered theories or ideas were linked (SG−−). Considering the SG− example in the table, discussing π-bonds requires students to remember that π-bonds are formed from two p-orbitals overlapping sideways on, that they are weaker than a σ-bond, and that they lead to a trigonal-planar (120°) bond angle around the central carbon atom, which means that the benzene ring, only containing π-bonds, is described as "flat". A large amount of previously discussed material is mentioned in one short sentence. The SG−− example not only contains a large amount of material that requires students to refer back to previous knowledge, but also contains discussion of electrons moving through space to create new bonds and the formation of new forms of the same intermediate; this requires complex thought and the use of an abstract context.

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J. Chem. Educ. XXXX, XXX, XXX−XXX

Table 3 shows how semantic density was coded. This analysis was also based upon previous work and related to the condensation of knowledge within sentences or paragraphs.[13−15] When coding sentences and paragraphs, if students did not require any previous understanding of complex chemical terminology, i.e., new words and phrases, they were coded as showing weaker semantic density (SD−−), but if many chemistry-specific complex words and phrases were used in an explanation, the semantic density was designated as stronger (SD++). An advanced term was defined as one that students were unlikely to have encountered in study prior to A-level. If a term was repeated within a phrase, it was only counted once. For example, the SD− example only requires students to understand one term, π-system; therefore, to follow the explanation, only one term needs to be unpacked. The sentence coded as SD++ contains six terms in quick succession that are all reasonably complex; a student needs to know what benzene is, what alkenes are and how they relate to π-bonding, what a cyclic arrangement is, the definition of aromatic (which has a different meaning in everyday life to within chemistry), and what it means when the term "π-electron" is stated. This is highly complex, and all terms need to be understood before the student can start to understand the explanation.

Examples of advanced terms are given in Table 4, and a full table of advanced terms is available in the Supporting Information. It was decided by the authors that terms students were likely to have encountered during their GCSE studies (exams taken in the UK aged 16) would not be coded as advanced, because students would likely have used these terms on a regular basis throughout their studies to this point and, so, should be part of their everyday chemistry lexicon. Terms that are introduced during A-level study, and more specifically are required when discussing aromatic chemistry in particular, were deigned to be advanced. Often, these advanced terms contain a Greek or Latin root and are an agglomeration of two other terms. For example, the term "nucleophile" is defined as "a reagent that forms a bond to its reaction partner (the electrophile) by donating both bonding electrons".[33] Students need to know this to understand the role of this particular reagent. In addition, the term nucleophile is derived from one Greek and one Latin term, *nucleus* (kernel, core; Latin) and *phileo* (I love; Greek), and is unlikely to be used outside of a chemistry context.

Table 4. Examples of Terms That Were Coded as Advanced

Terms Students Would Have Likely Encountered in Previous Study (e.g., GCSE)		Examples of New Terms Encountered at A-Level (Taken from the Transcripts)	
Atom	Hydrogen	Acylation	Induced dipole
Carbon	Ion	Anion	Lewis Acid
Catalyst	Molecule	Aromatic	Kekulé
Chlorine	Positive charge	Carbocation	Nucleophile
Double bond	Reaction	Catalytic intermediate	Ortho
Electron density	Repulsion	Delocalized	Para
Electron(s)	Ring	Dipole	π-Bond
Full octet		Hybridization	σ-Bond

The changes in sematic gravity and semantic density over time were used to form a semantic wave profile. This semantic wave profile was used to determine how complexity of language changed over an explanation, and if the participant aided the students in any way. For example, unpacking and repacking terms would lead to large semantic undulation and provide students with opportunity to further explore concepts and ideas. This is important, as it was shown by Mouton and Archer that the explicit use of semantic waves can show an improvement in the understanding of students.[7]

Once the transcripts were coded, the designations of words and phrases were put into Excel to show the strengthening or weakening of semantic density or gravity over time to provide a plot. These plots were smoothed to give a curve.

FINDINGS

In order to identify similarities and differences between explanations and across levels of study, short passages across transcripts in which participants were discussing the same chemical phenomena were closely analyzed and compared for strength of semantic gravity, semantic density, and exhibition of semantic waves.

Semantic Gravity

In a comparison of the participants, in some instances clear differences between university-level and high-school-level discourse could be identified. However, in some cases, the differences were minimal or not clearly linked to the level of the student audience. Two examples are discussed in more detail to illustrate where there are significant differences. The first example relates to discussion of the structure of benzene, Table 5, and the second example discusses the reaction between the aluminum(III) chloride catalyst and the chlorine molecule, Table 6.

When discussing the structure of benzene, participants with a university audience were coded as exhibiting weaker semantic gravity (SG−) than the school-based participants. For example, participant B (university) states that benzene is similar to an alkene in terms of reactivity but is slightly more stable due to its aromatic nature, but the definition of "aromatic" and why this is the case is not discussed, and students are expected to link back to their previous knowledge. Participant C (university) gives the students a

Table 5. Excerpts of Discourse to Show Differences in Semantic Gravity for Benzene Structure

Participant	Explanation	Designation
Participant B (university)	"...so in a similar way that alkenes can use their electron-density to behave as nucleophiles and attack electrophiles, benzene-rings can also do this. But because benzene-rings are more stable due to aromaticity, we need a stronger electrophile to be able to react with the electrons in the π-bond..."	SG−
Participant C (university)	"...looking at benzene it looks like a kind of cyclic-triene with three alkenes in this cyclic-arrangement here. But you know that benzene has aromatic-stability so if we count the number of π-electrons we have 2, 4, 6 so we have 6 π-electrons and six fits into the $4n$+2 formula which is Hückel's rule for aromaticity..."	SG−
Participant E (school)	"...this is our benzene-ring, and above and below the ring we've got this π-cloud of electrons, and this will become important in a second. In its delocalized form we have a flat-molecule so the six carbons are all in a plane with the hydrogens poking out of the side so all of these 12 atoms are in plane..."	SG+

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J. Chem. Educ. XXXX, XXX, XXX−XXX

Table 6. Excerpts of Discourse to Show Differences in Semantic Gravity When Discussing the Interaction of the Aluminum(III) Chloride Catalyst with the Chlorine Molecule

Participant	Explanation	Designation
Participant D (university)	"...lets draw our aluminium with its three valence electrons and then let's put our chlorines on, what do you notice about the aluminium in this compound? It doesn't have a full-octet. Yeah? So, it's got six valence-electrons and thinking about what we said about the Cl^{+}, what does that mean it can do? It can accept a pair-of-electrons. It is, a term for you here, a Lewis acid. When we're talking about Lewis acids and bases we're talking about electrons. Electron pairs mostly. So a Lewis acid is an electron-pair-acceptor. So try and remember that because you will come across that term. We will use it and you'll see it in textbooks and online. OK? So a Lewis acid is an electron pair acceptor. That's crucial in how it acts as a catalyst..."	SG−/SG+
Participant E (school)	"...aluminium chloride is our catalyst and this reacts with a chlorine molecule as a Lewis acid. The chlorine molecule undergoes heterolytic fission so the two electrons move over to one of the chlorines and that leaves us behind a Cl-plus which is the electrophile and Cl Al Cl 3 three minus which is the catalytic intermediate as well"	SG−−
Participant F (school)	"...to promote the formation of that dipole we also add in an aluminium-trichloride catalyst. Now if you think about the bonding in aluminium-trichloride it's a central aluminium-atom with three outer-shell electrons that forms three covalent-bonds with three chlorines. This means that this aluminium has only got six electrons in its outer-shell so it's got a gap ready to accept a pair-of-electrons, and that helps to promote this reaction···"	SG+

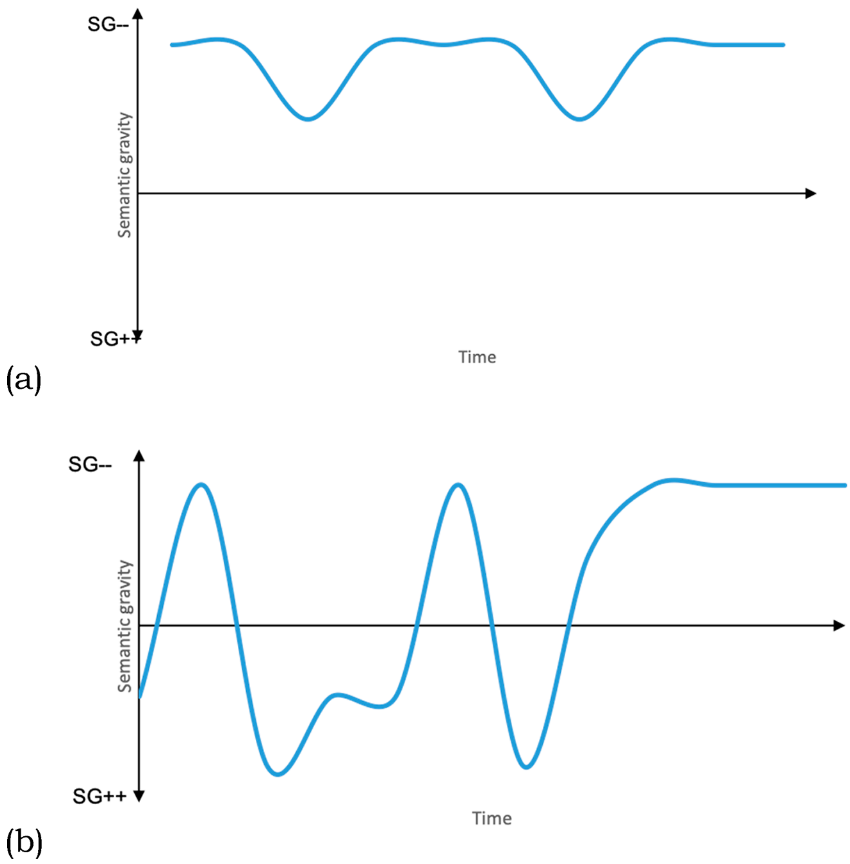

Figure 2. Plot to show the change in sematic gravity over time for (a) participant B (university) and (b) participant E (school).

large amount of detail about why benzene is aromatic and uses many concepts and ideas from earlier study, alkenes, cyclic arrangement, electron counting, and Hückel's rule, which add complexity to the explanation. In contrast, participant E (school) gives a very short, factual explanation about benzene and does not add any more information than is strictly necessary: Benzene has a π-cloud of electrons, and it is flat.

In contrast to the clear differences between school and university audiences across the passages outlined in Table 5, differences in strength of semantic gravity when discussing the role of the aluminum(III) chloride catalyst could not be clearly linked to audience level.

For example, participant D (university) spends a great deal of time explaining the reaction between the chlorine molecule and the catalyst, clearly outlining the role of the catalyst as a Lewis acid and explicitly linking back to earlier lecture content ("what does that mean it can do?") but explaining the term Lewis acid. A number of key concepts and ideas are linked, and large amount of time is spent explicitly on them (SG−/SG+). Participant E (school) does not explicitly state how aluminum(III) chloride acts as a catalyst, a stark contrast to their detailed explanation about the benzene ring structure. Students are expected to remember and understand the concepts of Lewis acids, heterolytic fission, and electrophiles without any additional explanation; the semantic gravity is weaker (SG−−). In contrast, participant F (school) explains the bonding in aluminum(III) chloride in very simple terms using cause and effect; the aluminum only has six electrons in the valence shell and therefore has a space that can accept two electrons. Therefore, semantic gravity was coded as stronger (SG+). Thus, three distinct approaches have been seen, where

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J. Chem. Educ. XXXX, XXX, XXX−XXX

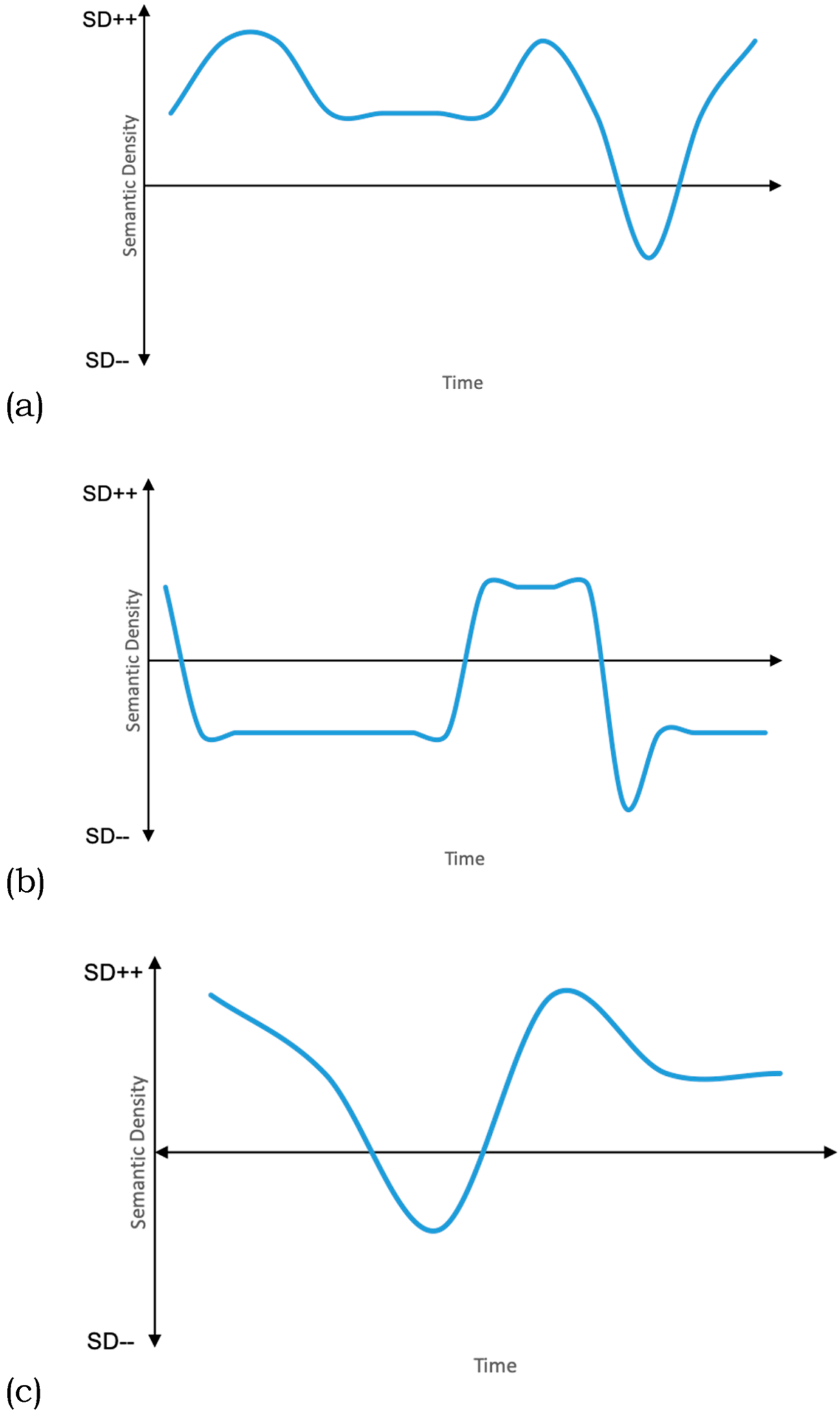

Figure 3. Plot to show the change in sematic density over time for (a) participant C (university), (b) participant D (university), and (c) participant G (school).

there is no clear link between the level of the audience and the semantic complexity of the explanation.

Semantic Gravity; Waves

Fluctuation in semantic gravity over time can be used to generate a semantic profile. Usually, a more undulating semantic profile was exhibited by the high school participants when compared with the university participants. All participants exhibited a semantic profile similar to participant E, and the semantic gravity "waved" from stronger to weaker over the explanation, crossing the x-axis a number of times. The one exception was participant B, who consistently used explanations that were weaker in semantic gravity (SG−), and students were expected to link back to previous study or ideas, which increased the complexity of the explanatory discourse. Not much time was spent fully explaining concepts, such as why the intermediate is charged or why rearomatization is important. When discussing the outcome of the attack of chlorine by benzene, participant B's explanation was as follows:

Table 7. Excerpts of Discourse to Show Differences in Semantic Density When Discussing Formation of the Carbocation Intermediate

Participant	Explanation	Designation
Participant A (university)	"...OK at this position the carbons now only have three bonds so it is positively-charged. So here's our *carbocation-intermediate*. And as I said for *benzene* the *π-electrons* are *delocalized* around the *system* we can also draw a *delocalized* version of this *carbocation-intermediate* so these would be called *resonance structures*. So let's look at the possible *resonance structures*..."	SD++
Participant C (university)	"...So this species here if you noticed that this carbon−carbon double-bond is next to this *carbocation* then you'll see that, we know that these *π-electrons*, because a *π-bond* is a weak-bond, these can move across here to form a *π-bond* here and this isn't an actual reaction taking place, this is *resonance*. So we draw this with the *resonance-arrow* here, so really here were drawing different depictions of the same thing. So if we move those *π-electrons* to there then it reveals that this carbon also has some positive-charge in this *intermediate*..."	SD++
Participant E (school)	"...So this carbon now had got four *σ-bonds* so it can't be part of the *delocalized-system* any more so the remaining four electrons which are still part of the *delocalized-system* they are only *delocalized* over the remaining five carbon-atoms so it's important to show this semicircle as in contact with all those five..."	SD+

"...So what we end up with here is our six-membered ring where we've formed a new bond to chlorine here—remember that we have hydrogens on all these positions—and because the electrons in this carbon−carbon double-bond have been taken by one of the atoms the other atom has lost a pair of electrons and is, as a result, positively charged..."

This explanation gives a large number of concepts and ideas all at once, electron movement, breaking bonds, forming bonds, and the loss of electrons by carbon to give a carbocation, but it is very short and succinct.

In contrast, the other participants spend much more time "unpacking" and "repacking" the explanations, spending more time on aspects they assumed that students would find difficult. When discussing attack by the benzene onto the chlorine molecule, participant E states:

"Electrons will come out of the benzene-ring and they will form a bond between the carbon and the chlorine, so our intermediate has still got the hexane of the benzene-ring and now because this is the carbon, that let's say, that the electrophile up here has attacked the π-cloud at the top means the chlorine will be above the plane of the ring so we show that with a wedge and that forces the hydrogen down below the ring, so we show that as the dashes. So this carbon now had got four σ-bonds so it can't be part of the delocalized-system..."

This explanation requires students to link the idea of electron movement with breaking a bond and to consider the three-dimensional outcome of this electron movement, but the outcome from the electron movement is explained; this is followed by further discussion about why the intermediate is positively charged.

Figure 2 shows representative semantic waves for participants B and E that illustrate the differences between complexity of explanations over the entire explanation.

Semantic Density

Generally, all participants across both educational levels exhibited stronger semantic density; i.e., the language used was complex and contained many advanced chemistry-specific terms. All participants exhibited some semantic undulation, but the majority of time was spent in the areas coded as SD+ and SD++. Therefore, the semantic wave was not pronounced and was similar in profile to those of participants C and G, Figure 3. This is unsurprising, as the lexicon required to discuss organic chemistry during A-level (high school) and university-level study requires a number of words and phrases that are specifically used to discuss chemical transformations.

The one exception was participant D (university), who exhibited relatively weaker semantic density overall when compared with the other participants. This is possibly because they consistently reiterated new terms and added further explanations using less complex terminology, so the density of complex terminology in a phrase or explanation was lower. For example, when discussing the role of aluminum(III) chloride as a Lewis acid, participant D (university) explicitly drew student attention to the term and repeated "Lewis acid" four times in one phrase:

"...It is, a term for you here, a Lewis acid. When we're talking about Lewis acids and bases we're talking about electrons. Electron pairs mostly. So a Lewis acid is an electron pair acceptor. So try and remember that because you will come across that term. We will use it and you'll see it in textbooks and online. OK? So a Lewis acid is an electron pair acceptor. That's crucial in how it acts as a catalyst..."

It was noted that, compared to the student audience's prior studies, for example, during GCSE study (aged 16) in the UK, the language required to understand an explanation of S_EAr was quite complex; there was a large lexicon of words that students were unlikely to have encountered previously, Table 7. Terms designated as advanced are in italics.

In this case, participant A mentions the carbocation intermediate and then moves swiftly onto the π-system in benzene that is delocalized and can therefore undergo resonance. To an experienced chemist, using the terms delocalization and resonance requires little or no clarification, but to a student who has only recently learned these terms, the complexity of meaning is relatively high (SD++). The same is true with participant C, where there is another discussion about π-bonds, carbocations, and resonance; these are again subject-specific, advanced terms. Finally, participant E discusses the fact that the Wheland intermediate is no longer a fully delocalized system due to the fact that that one carbon now has four σ-bonds. In all cases, what is meant by the term "delocalized" it not explicitly stated.

In comparison with semantic gravity, no clear differences can be discerned between education levels, and overall, all participants exhibited similar strengths of semantic density (SD+/SD++) and similar levels of semantic undulation.

■ DISCUSSION AND IMPLICATIONS

Some differences were identified across the explanations of school and university participants when considering semantic gravity. In this small study, the university-based participants exhibited weaker gravity (SG−) than school-based participants when explaining some concepts (e.g., the structure of benzene), linking together more ideas within a phrase or explanation, and linking back to previously encountered knowledge with no unpacking, assuming students could apply this unproblematically; there was minimal undulation of the semantic gravity profile. School-based participants generally exhibited more undulation than the university-based participants, and although links were made to concepts and theories that students had encountered previously, the school-based participants usually added further explanations to clarify what was meant during an explanation, unpacking and repacking the concept. This was expected because the school-based participants were likely to have only recently taught students the theories and concepts required to understand the explanation. In comparison, the university-based participants (with the exception of participant D, who taught on a foundation-level program) may have already expected students to be fluent with concepts and theories encountered at high school, so they spent less time unpacking and repacking them. Although perhaps unintentional, the use of semantic waves by the school-level participants has been shown in a previous study to give improvements in students' understanding of topics and can lead to significant improvements in the average marks of the cohort in summative assessment questions.[7] There were, however, also similarities in semantic gravity across levels of study, and when explaining some concepts (e.g., the role of the aluminum(III) chloride catalyst), differences in strength of semantic gravity between participants did not map to level of study of the audience. This lack of relationship between the level of education of the audience (i.e., school or university) in relation to the strength semantic gravity was unexpected; it was originally anticipated that those with a school-based audience would exhibit stronger semantic gravity, with more explanations of terms and concepts that would link back to factual recall and short explanations. The complexity of the sentences that the university-based participants used was also unexpected, considering S_EAr is a topic that is usually encountered early in the first year of study. In many cases, complex ideas and theories were explained using other complex ideas and theories, resulting in a weaker semantic gravity profile.

Regarding semantic density, the picture was one of similarity across levels of study, with both school-based and university-based participants exhibiting stronger semantic density and using complex chemistry-specific vocabulary to explain the chemical reaction. This was not entirely unexpected because the language used to describe a chemical transformation is largely the same once students reach high school and beyond. This links with Bernstein's characterization that the language of chemistry is "vertical discourse"; the language required to discuss more advanced topics increases in complexity, and language is not segmentally organized and requires prior knowledge.[10] However, the lack of semantic undulation by the school-based participants was unforeseen as it was expected that they would do more to "unpack" and "repack" terms over time, which would lead to waves of semantic density.

The findings overall across school and university participants (weaker semantic gravity, limited undulation in gravity level, and consistently stronger semantic density) have potential pedagogical implications for both high-school-level and university-level teachers with regard to possibly raising practitioners' awareness of the need for more undulation, both in semantic gravity and semantic density, of their explanations. It is likely that the students studying at high school will not have encountered the complex chemical terms and concepts used when explaining chemical transformations previously, or may not be completely confident or fluent in their use; therefore, time should be spent explicitly unpacking and repacking these ideas. It is recommended that teachers are concise when using chemistry-specific terms and draw students' attention to the use of a new term so that students become fluent with their use. In addition, at university, the increasingly diverse cohort of students studying programs means that the educational background of students is not homogeneous, and students may have differing exposure to the complex terms used due to different previous qualifications or countries of previous study. This should be taken into account when explaining a concept or idea, and sentences should be broken down to weaken the semantic density of an explanation, thereby lowering the cognitive load on the student.

In both cases, this work can be used in conjunction with Mouton and Archer's work to analyze lessons, lectures, and screencasts so they can be redesigned such that the semantic gap is narrowed and students' prior learning is considered.[7] In addition, the transition of language complexity as students progress through their studies should be brought to their attention so students are prepared and able to start improving their subject-specific literacy.

In terms of potential implications for specific-purposes language instruction, the findings contribute to understanding spoken discourse in the discipline. Beyond the large number of chemistry-specific terms that non-native chemistry students need to have mastered in English, students may also benefit from work analyzing spoken-language transcripts to identify where and how previous knowledge is drawn on to explain new concepts, and what language signals the unpacking and repacking of complex ideas within an explanation. This would enable students to develop strategies for more effective participation in lecture-style learning.

■ CONCLUSIONS

This study has for the first time investigated spoken chemistry discourse across school and university contexts, comparing the semantic gravity and density in spoken-language explanations of the same concepts at both levels. It has shown that there are both some key similarities and differences in the language used by teachers in high school and university when explaining electrophilic aromatic substitution. In all cases, semantic gravity was relatively weak, but the university-based participants generally exhibited weaker semantic gravity than the school-based participants, and less semantic undulation. The school-based participants usually showed greater semantic undulation by adding further explanations to clarify what was meant during an explanation by unpacking and repacking a concept. Both university-based and school-based participants exhibited relatively stronger semantic density and used similar subject-specific vocabulary regardless of the audience.

■ LIMITATIONS

This is a small-scale study, and as such, any findings should be taken as preliminary. The study does not take into account the explicit relationship between language and an instructor discussing a curly arrow formalism or diagram, which are both important when explaining mechanisms, nor does it explore individual differences in language use between the participants, or what the participant was explicitly trying to teach. This is the subject of further work, and outcomes will be published in due course. A larger study into oral discourse

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J. Chem. Educ. XXXX, XXX, XXX−XXX

in chemistry education could be undertaken, possibly including a contrastive analysis of the complexity of teacher and student explanations of chemistry concepts. This could facilitate better understanding of the causes of commonly held alternate conceptions within chemistry and allow educators to address them.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.0c00571.

Full list of terms for the S_EAr explanation with the categorization as either GCSE-level (encountered previously) or A-level (first encountered in high-school aged 18) (PDF, DOCX)

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Notes

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